Expert Provisioner: The Development and Implementation of a Knowledge-Based Decision Support Tool for Royal Air Force Reprovisioning

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Introduction and Overview

The Royal Air Force (RAF) operates a single echelon, centrally controlled inventory system to manage an inventory of approximately 855,000 line items; nearly 680,000 of which are consumables. Generally speaking, consumable items are those which are either consumed in use or are otherwise not economically reparable. Each of the consumable items in the RAF inventory is subject to reprovisioning as shelf-stock is consumed. During reprovisioning, Range Mangers (RMs) must take order quantity decisions that will minimise the risk of future stock-outs while also minimising investment. Successful consumable item reprovisioning requires a staff of RMs with a great deal of specific knowledge about item characteristics and customer requirements, coupled with a high level of expertise in reprovisioning procedures. Although the RAF Supply Central Computer System (SCCS) calculates proposed reprovisioning Order Quantities (OQs), Range Managers must review item provisioning parameters, demand trends and financial considerations before initiating procurement. Following the review, RMs have the difficult task of either accepting, based on their expert knowledge and judgement, or adjusting the proposed OQs.

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Although expert knowledge is crucial to the reprovisioning OQ decision, many Range Managers lack the years of experience needed to acquire the requisite level. This situation has arisen because of two primary factors. First, the RAF, like most other military organisations around the world, has experienced a significant manpower draw down during recent years, resulting in the redundancy of many of the RAF's most experienced Range Managers. Second, since Range Managers are relatively low-grade Ministry of Defence (MOD) employees, many of the best RMs seek and obtain early opportunities for promotion in other logistics support positions.

To address the problem, a knowledge-based system (KBS) called Expert Provisioner (EP) was developed to assist inexperienced RMs with the reprovisioning task. The literature is replete with definitions of a knowledge-based system. In the context of our work, we define a KBS to be "a computerised collection of simple rules that when used together, will emulate the decision process of an expert performing a complex task." The remainder of this article further details the problem being addressed, provides additional explanation as to why a KBS solution was pursued, overviews the functionality of the Expert Provisioner program, provides preliminary results and discusses the current status of the EP production system development effort.

The RAF reprovisioning system is a classical inventory process where a reorder point and order quantity is calculated for each item based upon item parameters and expected demand over the item lead (resupply) time.

RAF Consumable Item Reprovisioning

A brief description of the RAF consumable item reprovisioning process is necessary to frame our subsequent discussion of the Expert Provisioner KBS system. The RAF reprovisioning system is a classical inventory process where a *reorder* point and order quantity is calculated for each item based upon item parameters and expected demand over the item lead (resupply) time. When the serviceable balance for an item breaches the computed reorder point, a document called *Request for Requisition (R001)* is generated by the central computer system. The R001 document contains a proposed order quantity (OQ) for reprovisioning. The proposed OQ is calculated by the

central system using an Economic Order Quantity (EOQ) methodology.

The hard copy R001 document is forwarded to the RM responsible for the item for reprovisioning action. The number of fields (approximately 150) varies depending upon the number of existing requisition and contract records and the number of system-generated remarks.

Upon receipt of an R001, the Range Manager conducts a visual review of the item provisioning parameters to ensure accuracy. This task requires a great deal of expert knowledge. First, RMs must understand the meaning of the myriad of acronyms on the R001 document. Next, they must understand the impact of each of the parameters upon the OQ decision. In addition, they must be experienced enough to detect *suspect* parameter values that warrant further investigation. If the RM has all those skills, then he or she must be able to determine how the alteration of one or more of the item provisioning parameters will affect the item reprovisioning order quantity.

Arguably, determining the *right* reprovisioning OQ is a difficult task for even very experienced RMs. What makes the task even more difficult is that many factors that affect the order quantity are not provided on the R001. In addition to item parameter accuracy, RMs must often consider factors such as price-break opportunities, shifting demand patterns, customer ordering errors, budget constraints and varying order procedures in deciding upon the *right* reprovisioning order quantity. All these factors combined, coupled with the general low experience level among RMs, clearly makes the reprovisioning task very difficult.

Why a KBS Approach?

The literature indicates that knowledge-based systems are best suited for situations where expert knowledge is largely heuristic and uncertain.[1] This is clearly the situation often facing the Range Manager. In cases where KBS solutions are appropriate, the literature promises an impressive list of potential benefits.[2] With respect to our application, the following benefits are highly desirable:

Permanent, Online Source of Expertise

Range management is a relatively low grade, entry level position within the MOD with little opportunity for advancement. Thus, as mentioned earlier, after some experience is gained, RMs often seek transfer to other departments where they may gain broader experience to more quickly qualify for promotion opportunities. Since a KBS rule base effectively captures expert knowledge, the effect of this continuous loss of human expertise will be mitigated.

Accommodation of Business Dynamics

The RAF is currently in the process of developing its next generation Logistics Information Technology Strategy (LITS). During this transition period, numerous improved business practices are emerging, however, the existing legacy Information Technology (IT) systems are not being updated during the transition. A KBS can provide an IT platform for documenting and implementing emerging improved business practices in the interim period before the new IT system is delivered.

Intelligent Tutor

Knowledge-based systems can be designed to provide extensive advice messages, explanation and general information to assist and educate RMs as they use the system. In addition, because the rule base underlying a KBS is based on expert knowledge, the resulting decisions and recommendations are both consistent and explainable, thus lessening the negative effects of inexperience and human emotion.

EP Functionality and Program Structure

The initial development of Expert Provisioner was a joint effort by the RAF's Logistics Research (LR) Department and the Artificial Intelligence Applications Institute (AIAI) at the University of Edinburgh. Expert Provisioner was built in two phases.[3] First, a prototype system was developed. The EP prototype inference engine and knowledge base were implemented using the NASA C Language Integrated Production System (CLIPS) development tool. The prototype system served two purposes. First, it provided the RAF Logistics Research staff with the opportunity to learn about KBS via a *hands-on* development project. Second, the prototype development provided a technology demonstration tool that could be used to show RAF logistics decision-makers how a KBS approach could be used to assist the reprovisioning process. After the prototype system was completed and approved for further development and implementation, work began on an EP production system.

Overview of EP Production System Functionality

Like any system, EP consists of inputs, a process and outputs.

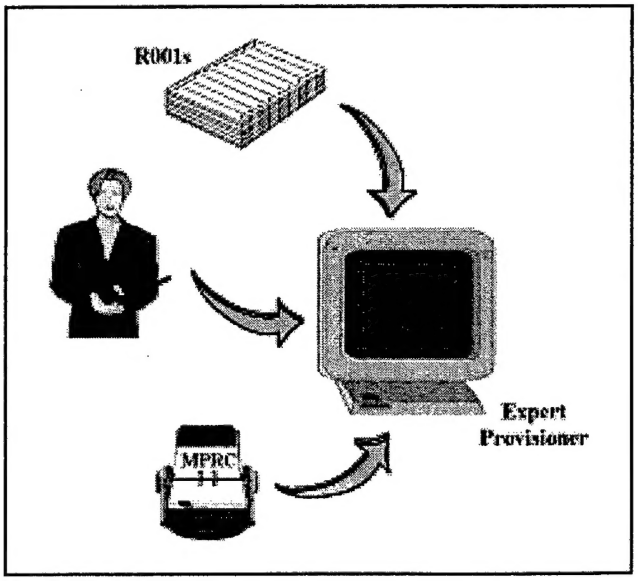

Figure 1. Expert Provisioner Inputs

EP Inputs

As shown in Figure 1, EP has three input sources: (1) the R001 document; (2) the Master Provisioning Record Card (MPRC); and (3) the Range Manager.

1. R001. The R001 provides a significant amount of item indicative data and provisioning parameter information. As part of our work, we were able to arrange for the electronic delivery of R001 data from the central computer system.

2. MPRC. The MPRC is literally a Range Manager-maintained card file of hand-written information about items. A single card exists for every item in the RAF inventory. The front

of the MPRC is used to record item indicative data and other information about item peculiarities. For instance, if a price break is available when large orders are placed, that information would be recorded on the MPRC. The back of the MPRC is used to record a history of item purchases. An electronic MPRC capability was developed as part of the EP production system. MPRC shells for each item in the RAF inventory are pre-loaded by the system. The shells contain as much relevant information as can possibly be extracted from SCCS item indicative data. Range Managers have to complete the records prior to when those items arrive.

3. Range Manager. Since much of the information affecting reprovisioning OQs is not available from the other two input sources, EP is designed to prompt Range Mangers for input as required. For instance, a rule in EP may detect a recent customer demand quantity that is inconsistent with an item's historical demand pattern. The program will provide the RM with an advice message and request confirmation of demand validity or the input of corrected demand data. In fact, the design of EP is purposely that of an *intelligent assistant* rather than an authoritative decision maker.

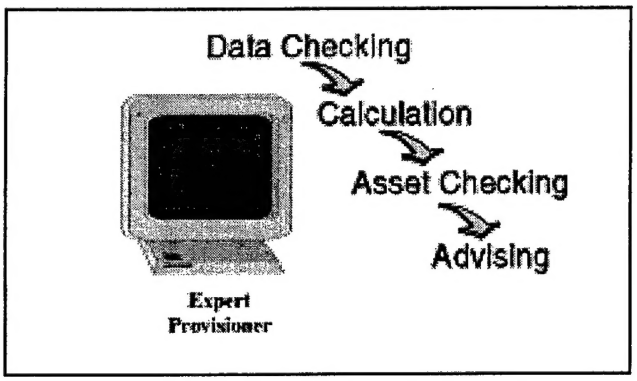

Figure 2. Expert Provisioner Rule Categories

EP Process

The processing that occurs within Expert Provisioner revolves around a rule base. The rule base development process is fairly straightforward. The first step is to identify a human expert who is highly experienced and proficient in the task of interest. Once identified, various knowledge acquisition procedures are used to transform the expert's knowledge into an orderly collection of rules for implementation in a computer program. The encoded rules are called the KBS rule base. As illustrated in Figure 2, there are four categories of EP rules: (1) data checking; (2) order quantity calculation; (3) asset checking; and (4) advising rules.

1. Data checking. The EP data checking rules are designed to focus on the item parameters that affect the order quantity calculation. For example, separate rules assess the input data elements pertaining to the accuracy and reasonableness of factors such as item administrative and purchase lead times, single and grouped demands, safety stocks and minimum buy requirements. As certain data errors are detected, EP will correct the erroneous parameter value and advise the user of the action taken. When suspect data is detected, EP produces a screen message asking the RM to investigate the potentially erroneous data and make input indicating the appropriate action.

2. Calculation. In the calculation phase, EP uses the rule-filtered provisioning parameters resulting from the data checking phase to calculate a revised reprovisioning order quantity. In addition, the EP calculation phase makes use of known price break opportunities (from the electronic MPRC) in computing the OQ. Although the item price is a key parameter affecting the OQ decision, the current central system calculation does not consider price breaks in the OQ calculation. Thus, this feature of the EP calculation phase is a significant improvement over current practice. It is also important to note that EP allows RMs to deviate from the system recommendations as they see fit.

3. Asset checking. Once an OQ is decided, Expert Provisioner uses a series of rules to search for existing RAF assets that may be used in lieu of purchasing additional stocks. These rules use data from the R001 and MPRC, in addition to databases containing disposed surplus stock records. When alternative assets are detected, EP advises the RM of where and how to obtain the stocks.

4. Advising. As mentioned earlier, the current central supply system is a legacy system that cannot be easily modified. Therefore, there are no direct electronic links between EP and the SCCS. Thus, when EP detects and corrects data errors as a result of the *firing* of data checking rules, RMs must process transactions on the central system to reconcile the item parameters on the SCCS. As the required changes are made in the data checking phase, EP creates reminder messages that are displayed during the advising phase. The update reminder messages provide the RM with all the information, including the transaction type and RAF supply manual references required to achieve central system data reconciliation. There are plans to implement an automated electronic message handling system to bridge this air gap.

EP Outputs

As shown in Figure 3 (see page 18) there are generally five types of EP outputs: (1) OQ recommendations; (2) data housekeeping assistance; (3) management and budget reports; (4) desktop analysis capabilities and help facilities; and (5) information messages. These aim to assist the RM throughout the process of reprovisioning.

Preliminary Results

Although EP is not yet fielded in all Supply Management Branches (SMB), we believe the system has already produced significant benefits. The benefits noted thus far resulted from the EP development process and from the Jaguar Supply Management Branch's trial implementation.

Developmental Benefits

In addition to being an excellent learning experience for the LR staff, the EP development process has resulted in both quantifiable and intangible benefits for the RAF.

Reduced safety stocks. During the rule base development process, we constructed a rule which checks that selected items supplied directly to RAF customers by contractors have a Depot Working Stock Level (DWSL) parameter set to zero as required by RAF procedures. A DWSL of zero ensures no depot safety stocks of the items are held. In December 1997, we conducted a spin-off analysis of supply central system data to discover that the vast majority of over 12,000 active direct supply items have

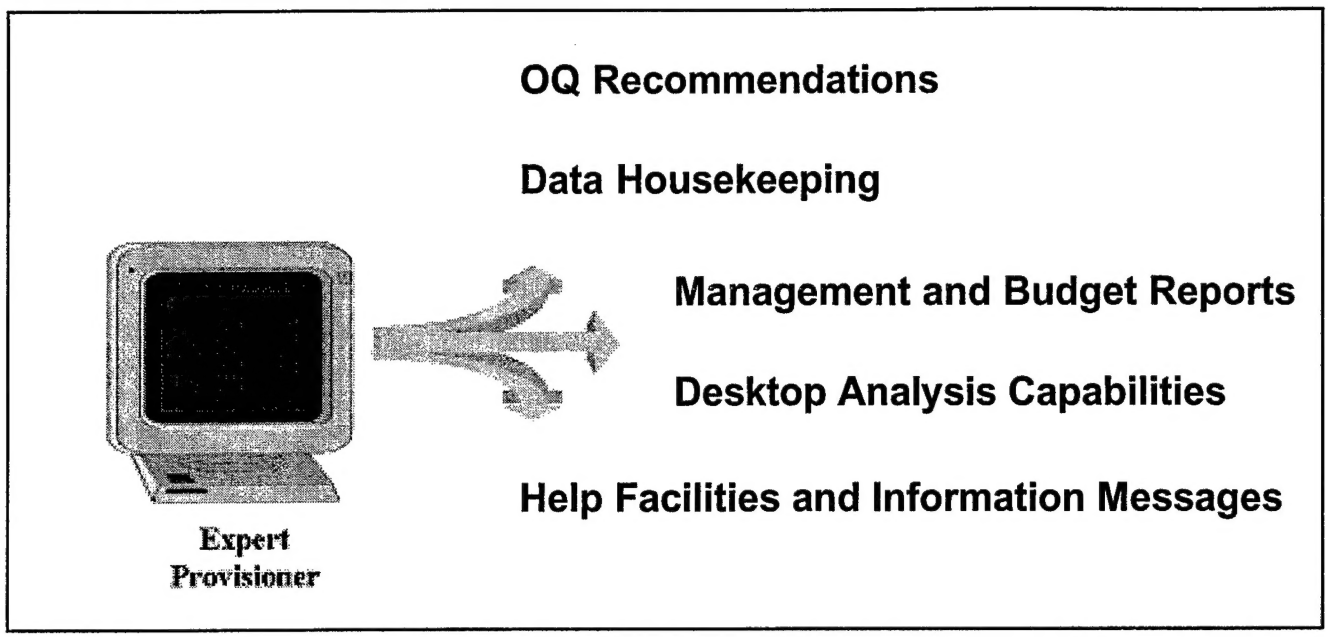

Figure 3. Expert Provisioner Outputs

DWSLs greater than zero. Further analysis revealed that the supply computer terminal screens did not allow Range Managers to input a DWSL value of zero. Because of the erroneous DWSL values, the RAF is currently holding more than £2.7M ($4.5M) in excess depot stocks. As a result of our analysis, the RAF supply policy staff directed a correction of the computer terminal screen input limitations and initiated a central system data sweep to correct the item DWSLs and preclude future safety stock procurements of direct supply items.

Surplus stock retrieval opportunities. A second significant benefit resulting from EP development involved RAF surplus stocks held by Military Aircraft Spares Limited (MASL). MASL is under contract to the MOD to act as the disposal agent for surplus assets. As the RAF disposes of surplus stocks, the stock balances are removed from SCCS records and recorded in the MASL inventory control system. Until MASL sells the surplus stocks, they are available for issue to RAF needs. However, since Range Managers do not have visibility of MASL stock balances, retrieval of MASL stocks seldom occur. In a spin-off analysis published in February 1998[4], we discovered that over the last two years, there were nearly 2,000 opportunities where the retrieval of MASL stocks could have fully, or partially, satisfied £1.3M ($2.16M) worth of RAF reprovisioning requirements. As a result we have implemented a rule that will use MASL data to detect the existence of available surplus stocks and preclude unnecessary procurement actions.

Electronic Requisition Requests

As part of the EP development process, arrangements were made for the creation and transmission of electronic R001 Request for Requisition documents. This capability speeds the delivery of R001s for Range Manager processing and could potentially lead to a significant reduction in paper printing and handling costs. It has also realised an estimated saving of some £681K ($1.128M) on work that would have been done under the LITS Tranche I Order Management software development effort.

EP Trial Implementation Benefits

A trial of the EP software was initiated in two Range Management cells in January 1998. During the trial, Range Managers processed their R001s without the benefit of EP and then later reprocessed the same R001s electronically through EP. The goal of this exercise was twofold. First, the trial was used to obtain feedback regarding EP functionality and usability. Second, trial data was used to assess EP's usefulness in detecting potential parameter errors and validating the effectiveness of the individual rules in EP.

User Feedback

As expected, the first month of the trial generated a great deal of feedback from the users. That feedback often led to adjustments in the software. In addition, we encountered and worked through computer hardware connection problems to successfully connect all trial participants to the EP software. Therefore, the analysis results from the first month were somewhat limited, but nonetheless, instructive. The customer feedback was clearly supportive of EP implementation. In general, the trial users advised that the rule base is robust and helpful. In addition, user feedback suggested that the program structure closely followed current R001 processing procedures. User feedback also indicated that EP provides important intangible benefits. Specifically, the trial highlighted EP's value in promoting user computer skills development, as a training aid and as a data analysis tool.

Computer Skills Development

Although many of the trial users are not PC-literate, they indicated the program is easy to use, and thus they are developing important rudimentary computer skills as they use EP. We believe that the computer skills acquired via the implementation of EP will significantly ease the implementation of LITS.

Training Value

A second intangible benefit of the EP trial implementation resulted from the existence of the numerous help features. The

trial participants advised us that these features are very useful, particularly to more inexperienced Range Managers. Clearly, using EP is improving Range Management skills in a way that will benefit the RAF logistics community in both the short and long terms.

Data Analysis Capability

The EP system includes the DataProv package, along with the data required to process desktop DataProv queries. EP trial users have advised us that they have used this capability extensively to identify and correct erroneous provisioning parameters that would not have been otherwise detected. Although not easily quantifiable, there is no doubt that those parameter corrections are improving the quality of subsequent provisioning decisions.

Trial Data Analysis

Although, the first month of the trial was a learning process with continuous program development, we were able to glean some useful data from the results in terms of rule base effectiveness and rule base update needs.

Rule Base Effectiveness

Analysis of a sample of 30 R001s that were processed during the first month of the trial (January 1998 data) revealed that seven of the 30 items satisfied all 10 criteria for automatic ordering qualification. This is an important result that has the potential to reduce RM workloads and streamline the provisioning process. Further analysis of the rule base performance for the 30-item sample indicated that, on average, EP highlighted 3.7 item parameters per R001 that required RM attention, compared with 2.7 flagged parameters for R001s processed without EP. We believe this result gives an early indication that the EP rule base performs a more accurate and comprehensive check of provisioning parameters than is being conducted by the RMs.

Rule Base Updates

Analysis of the trial data also indicated that additional rule base modifications and additions may be appropriate. For instance, one EP rule checks for price break opportunities *fires* for virtually every R001 and may need modification to prevent annoying EP users when price breaks are not applicable. We are also using the analysis results to determine if there are data checks that are not accommodated in the rule base. As such discoveries are made via analysis of the EP trial data, we will update the EP rule base to maximise the system benefits.

Future EP Development

Following the implementation of the EP production system, we anticipate expanding the rule base to incorporate functionality for assisting Range Managers in making repair quantity decisions for suitable items. Additionally, we envision the development of a data feedback link to the central supply system for the electronic passage of item parameter update messages. Finally, as mentioned earlier, the RAF is in the process of defining and implementing a new Logistics Information Technology Strategy (LITS). As the development of EP has progressed, LITS development personnel have expressed interest in integrating elements of EP into LITS. We are currently coordinating with the LITS office to determine how integration of EP may be taken forward as a decision support system for the new logistics IT system.

Expert Provisioner provides the RAF logistics community the ability to capture expert reprovisioning knowledge and implement that knowledge across the reprovisioning community in a way which promotes best business practices and trains inexperienced Range Managers while simultaneously improving order quantity decisions.

Summary and Conclusion

The initial implementation of EP within one of the four support management directorates, at RAF Wyton, was completed in July 1998 and significant business and financial benefits have already been realised. Those that can be measured total some £4.25M ($7.36M). This coverage will be expanded to nearly 100 percent of all RAF consumable managers with the delivery of a new IT platform, due in the first quarter of 1999.

We believe the continued development and implementation of the Expert Provisioner KBS represents a significant step forward in the efficient management of RAF consumable item inventories. EP provides the RAF logistics community the ability to capture expert reprovisioning knowledge and implement that knowledge across the reprovisioning community in a way which promotes best business practices and trains inexperienced Range Managers while simultaneously improving order quantity decisions.

In addition, EP provides the RAF with a flexible interim IT platform which can be used to implement new, improved reprovisioning procedures pending the delivery of the next generation RAF logistics IT system. The usefulness and benefits of applying KBS as described in the literature[5] would seem to have been realised.

Notes

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